# Radiological Weapons:

## How Great Is The Danger?*

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DISCLAIMER

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# *Radiological Weapons:*

# *How Great Is The Danger?**

*by George M. Moore*

## *Introduction*

President Eisenhower's Atoms for Peace speech in 1953 was greeted with worldwide anticipation of the benefits to mankind that would begin to flow from the peaceful use of the atom in multiple areas of technology. Although the release of nuclear technology under Atoms for Peace heightened concerns for the proliferation of nuclear-yield weapons, the feeling in 1953 was that the risks outweighed the benefits. For many years, this assessment of relative risks has been under review as proliferation concerns, driven by improvements in technology, have increased. However, it is only more recently that concerns about the nonproliferation uses of radioactive materials to injure persons or property have risen to the level of national and international debate. In contrast to the focus on national intentions in proliferation, these new concerns have focused primarily on the potential use of radioactive materials by terrorist or subnational groups.

Well before the September 11, 2001, attacks on the World Trade Center and the Pentagon, a significant concern existed that a terrorist group, or even a single individual, would use a radiological weapon (RW)[1] to attack people and property. September 11 clearly increased those concerns. Attention since September 11 has focused primarily on radiological dispersal devices (RDDs)—devices designed to spread radioactive material. The expression "dirty bomb" entered the public awareness through numerous media stories and has, in the public mind, become synonymous with RDD even though under most definitions a "dirty bomb" is only one example of an RDD. In addition to mounting concerns about RDDs, there are now heightened concerns about attacks on nuclear reactors, the spread of radioactive materials by non-explosive methods, and other uses of radioactive material to injure people and property.

Concerns about access to nuclear materials for malevolent purposes have prompted numerous domestic and international incentives to minimize risk to the population. For

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* This paper represents only the opinions of the author. It does not represent the views of the Center for Global Security Research (CGSR), Lawrence Livermore National Laboratory (LLNL), the University of California, the Department of Energy (DOE), or any other department or agency of the U.S. Government.

[1] The term "radiological weapon" (RW) has been used by a number of different authors. For this paper RW is defined as any device or method, except for a nuclear yield-producing device, that uses, or intends to use, radiation from the decay of radioactive materials to cause injury to persons or property by unlicensed exposure.

example, the International Atomic Energy Agency (IAEA)[2] recently held a conference in Vienna in March 2003 on these issues. Participants from member states and invited organizations were invited to focus on major topics that included:

- Recovering and securing high-risk, poorly controlled radioactive sources.
- Strengthening long-term regulatory control of radiological sources.
- Stopping illicit trafficking/border controls.
- Planning the response to radiological emergencies arising from the malevolent use of radioactive sources.[3]

How dangerous are RWs? Are RWs sufficiently dangerous to require regulations to severely curtail the availability and use of radioactive materials? Would restrictive regulations cause a rollback of many of the benefits that the widespread use of radioactive materials have brought to modern societies? Has Atoms for Peace created a world of unprecedented hazard, or can changes be made to deal with the threat of RWs while retaining the beneficial uses of radioactive materials?

One of the underlying purposes of this paper is to provoke thinking about the interplay between the regulation of radioactive materials and the risk of their use in an RW. Also considered in this paper is the nature of the threat and danger posed by the various types of RWs, the essential elements that must be considered in responding to the terrorist use of an RW, and what steps may need to be taken *a priori* to minimize the consequences of the inevitable use of an RW. Because RDDs have been the focus of so much recent concern and are the most probable RWs to be used by a terrorist group, a major focus in this paper will be on RDDs.

Finally, although as the IAEA conference illustrates that major efforts are underway to minimize the terrorists' ability to acquire and use RWs, we should address what programs and policies need to be considered under the assumption that a terrorist attack using radioactive material will almost surely occur in the reasonably foreseeable future.[4] Indeed, it can be argued that the apparent Chechen placement of a cesium 137 source in a Moscow park in 1995 was a first use of an RW.[5]

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[2] Created in 1957 as organization to carry out Atoms for Peace, the IAEA has provided international guidance for the peaceful utilization of nuclear materials under the auspices of the United Nations.

[3] "Tightening Security of Radioactive Materials," IAEA Worldatom December 3, 2002.

[4] A recent British analysis put the probability of such an event in the UK at 10% to 40% within the next 5 years. "Dirty Bombs: Threat And Response," Jane's Terrorism & Security Monitor, February 01, 2003.

[5] This widely reported event occurred in November 1995. A Chechen rebel commander told a Russian television station where a buried container of radioactive cesium could be found. See, e.g. "Russia Says Chechens a Nuclear Threat to U.S. Military," Agence France –Presse, January 30, 2003.

## *Radiological Weapons*

### Historical Perspective

Using radioactive material to injure is not new. Even before the development of nuclear weapons and reactors, harmful effects of the various types of radiation were understood. Serious considerations about using radioactive materials as weapons, however, is generally a post-World War II (WWII) issue simply because significant quantities of radioactive materials did not become available until the post-WWII era.

Considerable thought was given to radiation effects in the early Cold War era. After Hiroshima and Nagasaki questions were immediately raised about whether armies and navies could maneuver on what some believed would be the atomic battlefields of future conflicts. Significant efforts were made to answer these questions and to understand the effects of nuclear weapons. Direct radiation effects and the effects of radiation received from the radioactive materials produced by the detonation and transported as fallout were studied extensively. This information was widely disseminated to the general public and became part of Civil Defense planning in the United States.[6] The converse of the military's interest about whether access could be gained to an area where radioactive material was present was whether access could be denied to an enemy by intentional dispersal of radioactive materials. Apparently each nation that has considered area denial has come to the same conclusion: dispersal has little military value. Thus, no nation has ever seriously developed RWs as part of their military stockpile.

In contrast to the prereactor era when the only radioactive materials available were the infrequent materials found in nature or minute quantities made in an accelerator, radioactive materials are omnipresent[7] even in what would be considered very underdeveloped countries.

Nations' abilities to regulate and deal with radioactive materials vary over a broad spectrum. Under the umbrella of the IAEA, support is routinely given to less capable nations. Most governments have agencies whose purpose is to regulate radioactive materials and to protect the public in the event of an accidental dispersal of the material. In many countries, the military has the greatest ability to deal with radioactive material and even countries without nuclear weapons have militaries that have the ability to protect their forces and populations from the effects of nuclear weapons.

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[6] See, for example, Samuel Glasstone and Philip Dolan, *The Effects of Nuclear Weapons,* 3rd Edition, U.S. Government Printing Office, 1977.

[7] In the United States there are about 2 million devices containing radioactive sources, excluding those licensed directly by states and those used by the Department of Energy. Presentation by Richard A. Meserve, Chairman U.S. Nuclear Regulatory Commission at the IAEA Conference Buenos Aires, Argentina, December 11, 2000.

As we enter the early twenty-first century, the world is a place where radioactive materials are widely distributed, but where, until quite recently, little thought was given to the use of RWs. The focus of radiation control has been to prevent inadvertent injury rather than to establish systems to prevent intentional injury. Thus, for example, we clearly mark the location of radioactive materials and often indicate the exact type of material plainly. Clearly regulations of radioactive materials are being, and will be, revised to address current security concerns. Many of these regulatory concerns are currently under review in legislation introduced in the Senate by Senators Clinton (NY) and similar legislation sponsored in the House by Representative Markey (MA). The Clinton-Markey Dirty Bomb Prevention Act of 2002[8] would amend the Atomic Energy Act of 1954 to provide increased security for small sources.

## Effects Of Radiological Weapons

This section addresses the hazards posed by several types of RWs. The emphasis is on considering the lethality and the implications the various types of RWs have on planning for prevention and mitigation of an RW event.

### Radiological Dispersal Device (RDD)

The effectiveness of an RDD depends on its ability to disperse radioactive material and the hazard of the radioactive material used. The relatively few radioactive materials that have a significant probability of being used are shown in Appendix A.

Appendix B shows the results of an urban RDD scenario recently presented to the Senate Committee on Foreign Relations.[9] The scenario is one of the dispersal of a $^{60}$Co source from a food irradiation plant by an explosion at the lower tip of Manhattan. The underlying assumptions in modeling of this type depend on several key assumptions of questionable validity for dispersal [10] and effect.[11]

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[8] S.350 is a proposed bill that amends the Atomic Energy Act of 1954 "to strengthen the security of sensitive radioactive material." In essence the legislation would establish an ongoing task force comprised of cabinet level officers such as the Secretary of Defense and the Attorney General, who would recommend appropriate classifications of materials and security measures and meet on an annual basis to update their recommendations.

[9] Testimony of Dr. Henry Kelly, President of the Federation of American Scientists before the Senate Committee on Foreign Relations, March 6, 2002.

[10] Modeling assumes that an explosion will create a source term that can be input to a weather model. It appears that little research has been done on the explosively driven dispersion of radioactive material, but there are indications that the U.S. and Russia may be conducting trials of this nature. See, "U.S., Russia testing effects of 'dirty bombs,'" Charles J. Hanley, Associated S. F. Chronicle, March 15, 2003 at page A4.

[11] The models generally use Linear No Threshold (LNT) modeling, which assumes that whatever injuries (typically cancers per units of population) are observed in high-dose situations (such as Hiroshima and Nagasaki) project in a linear manner to the zero dose level. Thus, if a dose of 200 rem per person results in x cancers per 10,000 persons, a dose of 0.2 rem will result in x/1000 cancers for the same population. The LNT hypothesis allows for the calculation of additional cancers for any given release or exposure by using

Few RDD scenarios involve immediate deaths from radiation. The only immediate fatalities from an explosively driven RDD would probably be from the explosion itself or from the panic that might result from the fear of the radioactive material. Long-term fatality predictions such as "1 cancer death" per 100, 1000, or 10,000 depend on whether the LNT approximation for low-dose health effects is accurate.[12]

Economic consequences of an RDD depend on what clean-up level is required. Would or should Environmental Protection Agency recommendations for peacetime decontamination or, in the alternative, destruction of buildings apply? What about the levels in EPA Protective Action Guides?[13]This depends on the assumptions used for determining the risk of continued occupancy and the willingness to accept higher doses in the event of a radiological emergency as discussed further below.

## Reactor Or Fuel Storage Attack

Other than an attack by a terrorist team employing knowledgeable destruction of reactor safeguards and reactor components over a fairly lengthy occupancy of the key spaces of a reactor facility, it is difficult to envision a significant dispersal resulting from an attack on a Western commercial power reactor.[14] Research reactors, although probably far more susceptible to attack because they have far fewer security and safeguard systems, have far smaller core inventories, and their design generally precludes the failure of reactor systems from providing a dispersal mechanism for the core materials.

Could a *USS Cole* - style attack or a physical attack followed by the use of explosives cause a reactor accident on a nuclear-powered surface vessel or submarine? This is an area that needs careful analysis. Naval propulsion reactors are much smaller than commercial power reactors and may be less vulnerable to damage. However, the demonstrated ability of a terrorist group to bring a significant amount of conventional explosive material next to a ship's hull should not be ignored.

Could a terrorist group gain access to and use an aircraft to attack or bomb a nuclear reactor or nuclear powered vessel?[15] Are their other methods of attack that could be carried out by "sleeper" agents or by extortion of employees?

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simple ratios. Whether this effect is real (e.g., defining an area where 1 additional cancer per 10,000 people will occur) or even relevant for planning or evaluation purposes is an open issue in dealing with RWs.

[12] As will be discussed further, even if the assumptions were accurate, the implementation of a post-event screening medical program might far offset the radiation-induced cancers.

[13] The EPA has developed a set of Protective Action Guides that apply to nuclear incidents. Guidelines indicate evacuation of the general population at 1 rem and relocation at 2 rem.

[14] The Chernobyl incident showed the world a worst-case example of what an extremely effective attack on a reactor facility might achieve. However, the RBMK-1000 reactor at Chernobyl was uniquely susceptible to burning and expelling a large portion of its core. Similar in principle to the much smaller British reactor involved in the Windscale accident, the RBMK-1000 was graphite moderated, and the burning graphite and fuel provided a viable method to disperse literally tons of radioactive material.

[15] Shortly after September 11th there was much concern about the crashing of a large jet aircraft into a reactor, but several analyses have pointed to the fact that the reactor's containment building would probably withstand the impact. It should also be pointed out that the piloting skill level required to impact

At almost every power reactor there exists the on-site storage of spent (burned-up) fuel. The spent fuel rods are highly radioactive and have always been considered to be self-protecting because removal of the spent fuel rods from their storage pools without the use of massive shielding would result in lethal radiation doses. Can explosive be emplaced in the storage pool to create a significant dispersal? This is a questionable proposition. Although rupture of the cladding of the fuel rods would release many of the gaseous fission products in the spent rods, there would probably be little driving force to release a significant fraction of the radioactive materials.[16]

The size and weight of the spent fuel rods themselves are inhibiting even if the person(s) attempting to remove them to use in an RDD are suicidal. Could a rod or two be removed from a pool and packed with explosives before a suicidal terrorist was incapacitated? Such a scenario should be carefully studied.

### Attack On A Disposal Site

Disposal sites come in all sizes and shapes. Most disposal sites provide some security, and the method of disposal usually does not allow easy access to the stored material, making it difficult to disperse from the site. In addition, disposal sites are generally remote enough that a dispersal would not create a significant risk of injury or property damage.

Removal of materials from a site to disperse at a target location is an item of concern particularly when the disposal site is abandoned and removal might be done by unobserved excavation. Although considered a problem primarily for disposal in the FSU, there are some water disposal sites used by the United States that should be examined to see if modern techniques of underwater recovery would allow the retrieval of materials that might be useful to a terrorist.

### Intentional Irradiation Without Dispersal

Examination of Table 2 in Appendix A shows that there are numerous sources in the IAEA's Category 1 that can deliver dose rates over 1 Sv or 100 rem per hour at a distance of 1 meter. Such sources are capable of delivering a fatal dose in about 4 hours of exposure.[17]

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the containment building might be considerably higher than that required to hit the World Trade Center. Relatively lower-speed suicide aircraft in WWII frequently missed ships that were much larger than containment buildings. However, ships maneuver and defended themselves, tasks that containment buildings cannot perform.

[16] Most of the gaseous fission products are relatively short-lived, and many reside trapped in the fuel material. The quantity released would depend on many factors that are difficult to predict, but little would probably be released unless the driving explosive was massive.

[17] There have been several tragic incidents where unintentional exposures from large sources have caused injuries. Typically the source has been lost or abandoned, and poor and/or ignorant people have taken the source for its value as scrap metal, usually opening it out of curiosity. In Goiania, Brazil, four people were

High-strength sources could be emplaced in a public location such as a movie theater or on a train, cruise ship, or other relatively unguarded location where people congregate and could deliver fatal doses with no notice to the victims. Radiography sources would be particularly well suited for this use because they afford protection to the terrorist until a decision is made to remove the source, open a shutter, or create exposure in the same manner that the device is designed to be operated to deliver radiation.

The suicidal or near-suicidal emplacement of an unshielded high-activity source could prove far more lethal than a radiographic source because the strength of the source is often far higher. The sources in many high-activity devices, if removed from their shielding, are small, easily transportable, and only detectable by radiation detectors.

### Summary Of Effects

RDD is capable of creating significant economic damage, but it is unlikely to create significant acute or long-term injury to persons. The intentional exposure with a high-activity source can potentially create numbers of acute and long-term injuries, but is generally not damaging to property. Attacks on reactors and disposal sites although potentially capable of injury are, like RDDs, chiefly of concern due to their economic effects but may cause lethal injuries to persons close to the reactor and/or to incident responders.

## Programs To Prevent RWs

What can be done to prevent the terrorist use of RWs? If regulators adopt the attitude that any program must be absolutely failsafe, it will undoubtedly result in Draconian restrictions that severely curtail or eliminate the use of radioactive materials. Although a failsafe program seems a laudable goal, it must be recognized that zero risk is not a realistic goal. Although the possibility of misuse of nuclear technology can be minimized, it will always exist. Establishing a program based on an unrealistic goal may result in a program that is more dangerous in the long run because a program that is too focused on prevention may ignore the need to prepare for mitigation. Any prevention program must reflect the global aspects of the threat of radiological weapons and must represent a cost-effective tradeoff between the risks of beneficial usage of nuclear technology and the threat of misuse, and must also provide a realistic program to deal with the actual use of radiological weapons.

The IAEA has begun to develop recommended programs.[18] Such programs concentrate on "cradle to grave" tracking of radioactive materials, getting orphaned sources back under control, increased security regarding who handles materials, and increased inventory requirements.

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killed and others injured by a cesium-137 source, and recently villagers in Georgia were injured when they found an abandoned Soviet-era RTG.

[18] "Security of Radioactive Sources – The Evolving New International Dimensions," Abel J. Gonzalez, IAEA Bulleting 43/4/2001

Many countries will undoubtedly view the IAEA methods as insufficient, not because they are not good ideas and good programs, but because the risks of RWs are sufficiently high that countries such as the United States will feel the need to implement more restrictive regulations.

The United States is engaged in significant efforts to aid other nations in preventing illegal trafficking in materials that could be used for a nuclear-yield weapon. These efforts have not been specifically expanded to include RWs, but many of the aspects of what is done to prevent the use of a nuclear-yield device in the United States would also help to prevent the use of RWs. RWs are probably far more detectable than source materials for a nuclear-yield device at border crossings, in shipping, and in the various ways that items can enter the United States. In contrast to the relatively low-radiation-signature materials of used in nuclear weapons, RWs are "hot," and more easily detectable.

Incorporation of enhancements in security, reporting, accessing and controlling of radioactive materials and the additional burdens they create are necessary results of a response to the apparent increase in threat. Although these foreseeable increases in regulations will have an impact on current users of radioactive materials, there must be an acceptance of the fact that the world has changed with regard to the necessary levels of security.

Future production of radioactive sources can be done in ways that would make the radioactive materials far less accessible or useful in an RW. Governmental programs to underwrite the cost of removing existing less-secure sources from service and replacing with more secure sources should be considered.

Radiation monitoring by agencies that have heretofore not played a role in monitoring such as the police (who now perform monitoring in selected areas such as New York City) and postal employees needs to be increased. This would have the benefit of potentially locating materials or devices before they could be used, but would also increase the awareness of what materials are now in the environment. Similarly, incorporation of radiation sensors into the environment should be done. Smoke detector/radiation detector combinations should be developed and required by building codes, and replacement/exchange programs should be developed to speed the widest dissemination of radiation detectors in places where the public gathers.

Finally, one aspect of prevention that is often overlooked is development of an informed public. This would not only aid in heightening the awareness of potentially illegal activities with radioactive materials, but would also minimize the risk of panic casualties when an RW is used.

## Programs To Minimize the Impact Of A Radiological Weapon

Preplanned programs to minimize the impact of the use of RWs are vitally necessary to protect people and the economy.

### Medical Programs

Medical treatment programs for radiation accidents and nuclear weapons casualties are not new. However, the end of the Cold War, lack of funding, and new generations of medical personnel require an ongoing training program for dealing with medical treatment for exposure and contamination.

In contrast to the large numbers of casualties anticipated from a nuclear-yield device, the treatment numbers from an RW would probably be low, allowing for better levels of treatment on an individual basis. Since only a few radioactive materials are likely to be encountered, programs should be developed to deal with removal of these materials from the body both internally and externally.[19]

Exposure standards for the emergency associated with RWs need to be developed and implemented. Use of peacetime standards for treatment would probably flood medical facilities. Emergency workers and medical personnel need standards that apply in such situations both for their own protection and for the treatment of casualties.

Training every emergency doctor and emergency team and crew to deal with RWs may not be either a realistic or desirable goal. Whether rapidly deployable national or regional teams would be best for primary or supplemental treatment should be evaluated and the appropriate responses funded.

Finally since the long-term effects of low-dose exposure are not well known or probably ever knowable, a conservative method of post-event medical monitoring should be developed to provide early detection and treatment for those exposed in an RW event.

### Decontamination

Similar to the medical need for pre-determination of allowable exposure levels, methods for decontamination need to be developed that will work after RWs have been employed. The current EPA cleanup standards may be far too costly in a metropolitan area if the contamination is widespread. However, it is apparent that very little is known about how to deal with contamination is an urban area like Manhattan. Should there be controlled evacuations in response to RWs? What level of contamination will require evacuation,

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[19] For example, there has been a recent interest in using "Prussian Blue," ferric hexacyanoferrate, to remove cesium 137 and other radioactive materials from the body. "The Dirty Bomb Blues," Wall Street Journal Online, February 4, 2003.

protective procedures, or long-term cleanup? Are we willing to spend what could be tens or hundreds of billions of dollars to lower an uncertain cancer rate of 1 in 1,000 by a factor of 10?

More than paper studies are required. Cleaning procedures and materials need to be developed and tested. Is it easier to seal an area by resurfacing or painting than it is to clean the area? Can leaded paints be used to reduce dose from contaminated surfaces or are the risks of using such materials too great?

Are the risks low enough that some combination of occupancy and cleanup could be done at certain levels of contamination? Are there techniques and methods that could prevent the functioning or minimize the contamination from an RW if one were discovered prior to its use?

Because the primary impact of RWs may be economic and intimately tied to decontamination, these programs need to be well understood and tested.

### The Need For Pre-Event Planning For Economic Loss

Regardless of how well any government deals with the medical and physical response to a radiological weapon, there is a need for preplanning for the economic consequences of such an event. The September 11 experience pointed out some of the problems that need to be addressed.

In one sense, the events of September 11 were, except for the severity, conventional events. While no one anticipated the method of the World Trade Center attacks, airlines, property owners, and individuals were able to obtain insurance that operated to offset their losses. Despite the existence of insurance, it was obvious that the World Trade Center attack would have overloaded the civil tort system and probably driven the airlines involved into bankruptcy if the September 11 Victims Compensation Fund of 2001 and the Air Transportation Safety and System Stabilization Act had not been implemented.

In contrast to the World Trade Center incident, most insurance policies have radiation-contamination exclusions in property damage coverage and many, if not most, policies now exclude coverage for terrorist acts. Currently, the only recourse most property owners would have in the event of business disruption or long-term or permanent damage to their property by contamination would be the much-maligned civil tort system. Resort to the civil tort system would undoubtedly involve sordid attempts to find a “deep pocket” to pay for the damages and would result in a tremendous waste of resources.

For the economy to function smoothly, there must be federal assurances that losses suffered from an RW can be covered. Federal involvement in anticipation of nuclear-related damages is not new. The often-maligned Price-Anderson limitations on liability for reactors are an example of prior federal policy making.

## The Impact Of The Suicidal Terrorist

The willingness of some terrorists to die for a cause must be recognized in all considerations regarding RWs. Is death by radiation acceptable to a suicidal terrorist? Whether there is a difference between the willingness to die instantly as a suicide bomber like those seen in Israel, in the Marine Barracks attack in Lebanon, and in the World Trade Center and Pentagon attacks and the slower death that would result from a fatal radiation exposure is something that needs to be explored.

Clearly the willingness to suffer high-level exposure or death increases the potential risk that an unshielded source could be used with lethal effect. The self-protection considerations that have always been argued in protection of spent reactor fuel and the theft of high-activity sources may need to be examined and protections upgraded if justified. The idea that the employment of an RW would include a significant lag time between placement and triggering of any device must be re-examined to consider the effect of suicidal intent.

# *Conclusion*

Radiological Weapons are going to be used by some individual or group, if not this year then next year, or at some time in the foreseeable future. A policy of focusing resources solely on prevention of their use would leave any government open to significant economic disruption when the inevitable use occurs. Preplanning can limit the injuries, property damage, and economic losses that might result from the use of a radiological weapon. Moreover, a combination of efforts to prevent and to minimize the impact of radiological weapons may significantly discourage potential users.

The dangers from radiological weapons can be dealt with while society continues to enjoy the benefits of nuclear technology that were promised under Atoms for Peace. However, some restructuring of our use of radioactive materials is necessary to ensure that the current and future uses of radioactive materials outweigh the potential disruption caused by misuse of the materials in radiological weapons.

# Appendix A

## *Radioactive Materials Available for Use in a Radiological Weapon*

The man-made radioactive material produced in nuclear reactors represents the bulk of the material available as a potential source for a radiological weapon (RW). Most natural radioactive materials do not have specific activity levels high enough to allow it to be used in a meaningful way in an RW without significant further processing and concentration.

The criteria that make radioactive materials commercially useful are a relatively long half-life (on the order of years and tens of years) and useful decay energies.[20] Fortunately there are a limited number of good commercial candidates and therefore there are only a few radioactive materials that are potential sources for an RW. Table 1 lists the most common isotopes and their characteristics.

**Table 1: Isotopes commonly used in sealed radioactive sources.** [21]

| Isotope | Physical Form | Half-life | Emission |
|---|---|---|---|
| Cesium-137 (Cs-137) | Solid (powder) | 30.1 years | beta<br>gamma |
| Cobalt-60 (Co-60) | Solid (metal) | 5.3 years | beta<br>gamma |
| Iridium-192 (Ir-192) | Solid | 74 days | beta<br>gamma |
| Krypton-85 (Kr-85) | Gas | 10.8 years | beta<br>gamma |
| Radium-226 (Ra-226) | Solid | 1600 years | alpha<br>gamma |
| Strontium-90 (Sr-90) | Solid | 28.8 years | beta |

Some of the isotopes in Table 1 are generally only found in certain types of applications whereas some, such as $^{137}Cs$ and $^{60}Co$, are so useful that they are used in many types of commercial devices. The IAEA has categorized the common commercial devices containing radioactive materials into three categories based on the IAEA's assessment of the source's hazard. Under the IAEA ranking system Category 1 devices are the most dangerous. Table 2 below shows the IAEA's Category 1 list. Table 2 lists the type of device; typical activity strength for that type of device, and a dose rate at 1 m from an unshielded source is presented based on the highest source strength for that device.

[20] Medically useful isotopes may have very short half-lives, as may other useful isotopes (e.g., tracers), but the bulk of radioactive materials that are in devices used in industry is characterized by relatively long half-lives.

[21] Table 1 is taken from "Commercial Radioactive Sources: Surveying the Security Risks," Charles D. Ferguson, Tahseen Kazi, and Judith Perera, Center for Nonproliferation Studies, Monterey Institute of International Studies, January 2003 at p.9.

**Table 2: IAEA Categorization of Radiation Sources by Risk Categories[22]**

**Category 1**

| Practice or application | Radionuclide | Decay energy [keV] half-life | Typical activity | Dose rate at 1m[a,b,c] [mSv/h] | Time at 1m[a,b,c] to exceed 1mSv |
|---|---|---|---|---|---|
| Teletherapy | Co-60 | γ (1173; 1333)<br>β (max.: 318)<br>$T_{1/2}$ = 5.3 a | 50–400 TBq | 8 E+04 | < 1 s |
| | Cs-137 | γ (662)<br>β (max.: 512)<br>e (624)<br>$T_{1/2}$ = 30 a | 500 TBq | 3 E+04 | < 1 s |
| Blood irradiation | Cs-137 | γ (662)<br>β (max.: 512)<br>e (624)<br>$T_{1/2}$ = 30 a | 2–100 TBq | 6 E+03 | < 1 s |
| Industrial Radiography | Ir-192 | γ (317)<br>β (max.: 675)<br>e (303)<br>$T_{1/2}$ = 74 d | 0.1–4 TBq | 4 E+02 | 9 s |
| | Co-60 | γ (1173; 1333)<br>β (max.: 318)<br>$T_{1/2}$ = 5.3 a | 0.1–5 TBq | 1 E+03 | 3 s |
| | (Cs-137)<br>(rare) | γ (662)<br>β (max.: 512)<br>e (624)<br>$T_{1/2}$ = 30 a | | | |
| | (Tm-170)<br>(rare) | γ (84)<br>β (max.: 968)<br>$T_{1/2}$ = 129 d | | | |
| Sterilization and food preservation (Irradiators) | Co-60 | γ (1173; 1333)<br>β (max.: 318)<br>$T_{1/2}$ = 5.3 a | 0.1–400 PBq | 1 E+08 | < 1 s |
| | Cs-137 | γ (662)<br>β (max.: 512)<br>e (624)<br>$T_{1/2}$ = 30 a | 0.1–400 PBq | 2 E+07 | < 1 s |
| Other Irradiators | Co-60 | γ (1173; 1333)<br>β (max.: 318)<br>$T_{1/2}$ = 5.3 a | 1–1000 TBq | 3 E+05 | < 1 s |
| | (Cs-137)<br>(rare) | γ (662)<br>β (max.: 512)<br>e (624)<br>$T_{1/2}$ = 30 a | | | < 1 s |

[22] Table 2 is taken from IAEA-TECDOC—1191, International Atomic Energy Agency, December 2000 at p. 13-16.

As part of their recent study of the risks of commercial radioactive materials, the Monterey Institute took abstracts from Table 2 and converted the activity levels from Bequerels to Curies.[23]

The Monterey Institute's analogous table also includes Radioisotope Thermoelectric Generators (RTGs) in Category 1, listing a strontium 90 source strength of 1.11 PBq to 11.1 PBq.[24] The RTGs are also powered by $^{238}Pu$ and are used in a number of applications, some of which involve leaving them unattended in remote areas.[25]

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[23] "Commercial Radioactive Sources: Surveying the Security Risks," Charles D. Ferguson, Tahseen Kazi, and Judith Perera, Center for Nonproliferation Studies, Monterey Institute of International Studies, January 2003 at p.13-14.

[24] *Id.* at p. 13.

[25] Although these sources are typically listed as pure alpha or beta emitters they can generate a considerable penetrating x-ray dose that results from Bremstrahlung interaction with the device's shielding. Alpha emitters can produce a significant number of neutrons via an $(\alpha,n)$ reaction on available oxygen.

# *Appendix B*

## *RDD Scenario*

Figure 1, below, shows the results of an RDD scenario based on an explosively driven dispersal of one of the $^{60}Co$ elements taken from a food irradiation unit.[26] The detonation site is the southern tip of Manhattan.

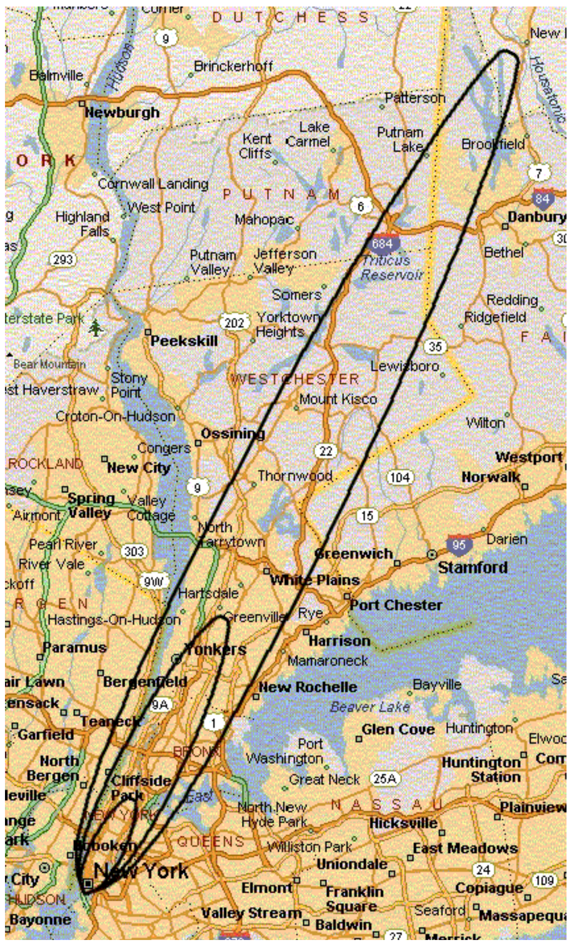


**Figure 1: Long-term Contamination Due to Cobalt Bomb in New York City- EPA Standards**

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|---|---|
| **Inner Ring:** | **One Cancer death per 100 people due to remaining radiation.** |
| **Middle Ring:** | **One Cancer death per 1,000 people due to remaining radiation.** |
| **Outer Ring:** | One Cancer death per 10,000 people due to remaining radiation.EPA recommends decontamination or destruction |

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[26] Figure 1 is taken from Testimony of Dr. Henry Kelly, President, Federation of American Scientist before the Senate Committee on Foreign Relations, March 6, 2002.